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SP212 Lab: Introduction to Electrical Measurements
Version: 7 January 2004

Introduction to Electrical Measurements

Introduction In each of the first eight labs this semester, we will be making *electrical measurements*. To make those measurements, we will either use a *digital multimeter* or the *computer* and thus part of what we will do in this lab is to learn how to use each of those instruments. However, since it is very early in the semester and since we haven't yet studied many topics in class, we will also need to learn about what it is that we are measuring. Fortunately, that is not too difficult since we are all heard of the first quantity that we shall learn about and measure, *voltage*. For example, we all know that voltage is associated with batteries since a modern car uses a 12 volt battery, many flashlights use 1.5 volt batteries, etc. The other two quantities that we shall deal with in this laboratory, *electric current* and *resistance*, are not quite so familiar. Nonetheless, we will make an attempt to both learn about and learn how to measure these quantities. In fact, this laboratory could be of great value to you. For example, the ability to use a multimeter is a skill that can make the difference in a military mission and can save you thousands of dollars over a lifetime. The reason is that, in the Navy and in life, you will encounter many malfunctioning electrical systems and a multimeter is the fundamental tool for troubleshooting electrical systems. Hopefully, some of the applications of a multimeter will be apparent by the end of this lab.

I. Voltage (Sections 23-1 and 25-1 in the textbook) Our first goal in this laboratory is to learn what *voltage* is. Some insight can be gained from an alternate (equivalent) name for voltage, *electric potential difference*.

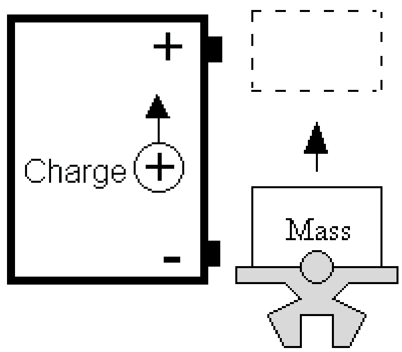
- The word "electric" distinguishes electric potential difference from other types of potential difference. For example, gravitational potential difference is sometimes defined. However, since we will not be concerned with anything other than electric potential difference this semester, we will use potential difference and electric potential difference interchangeably. Consequently, both terms will be synonymous with voltage.

- The word "difference" is used because voltage always exists between two different points (places). This makes sense because there are two terminals of a battery, for example.

- The word "potential" suggests the possibility that potential energy is involved. In fact, that is correct as will now be described for the special case of a battery.

Consider the cross section of a battery (turned on its side) shown in the picture on the left in the next diagram. Also shown is a positive charge inside the battery. It might be useful to think of the charge as "massless" since what the battery does to the charge has very little to do with the mass of the charge. What the battery does is use an electrochemical process to push or pull the "massless" positive charge from the negative terminal to the positive terminal. (Since like charges repel and unlike charges attract, the positive charge would not proceed from the negative terminal to the positive terminal "on its own.") Consequently, the battery causes an *increase* in the charge's electric potential energy.

What the battery does to a charge is *analogous* to a person increasing a mass's *gravitational* potential energy by lifting it to a higher elevation. The analogy is shown in the picture on the right in the next diagram. As we learned last semester, the gravitational potential energy gained by the mass can transform into other types of energy. A typical example is a freely falling object where a decrease in gravitational potential energy is accompanied by an increase in kinetic energy. Analogously, the electric potential energy gained by the charge (because of the battery) can transform into other types of energy. For example, as a charge moves through a resistor its electric potential energy decreases and heat is generated.



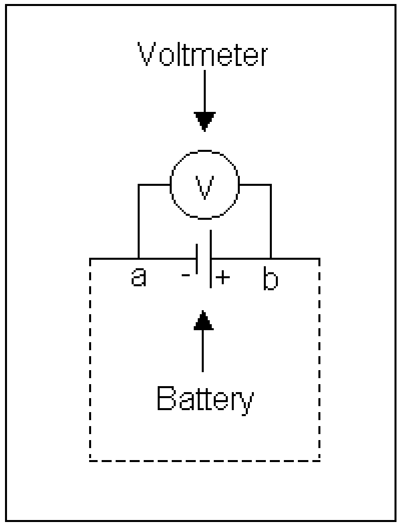
The important concept is that voltage is associated with any process where the electric potential energy of a charge *changes*. In addition, the voltage (of a battery, for example) does not depend on (is independent of) the charge. Consequently, we can define voltage as follows.

If a charge moves between two points, the *voltage* is **defined** as the *change in electric potential energy* of the charge *divided by the charge*.

Note: There is a special name for the voltage produced by a battery (and some other devices). That term is *electromotive force* or simply emf. As pointed out on page 659 in the textbook, the terminology electromotive force is unfortunate since electromotive force, itself, is not a force. This should be apparent from the fact that the unit of emf is the **volt** (V), the same as for voltage. There are, of course, electric forces involved in the electrochemical process. However, to avoid confusion, we will just use the abbreviation emf.

Measuring a Constant Voltage Our second goal in this lab is to learn how to measure voltage. Because of the definition of voltage, it probably is no surprise that voltage is always measured *across* a device i.e. between two different points. (Sometimes this is referred to as putting a measuring instrument in *parallel* with the device.)

A symbolic representation of measuring a voltage across a battery is shown in the next diagram. (The dashed lines represent other devices that, together with the battery, form a "circuit." Circuits will be discussed later in this lab.) The circle containing the "V" represents our measuring instrument and is often referred to as a *voltmeter*. For us the voltmeter will either be a multimeter or the computer configured to measure voltage. Our first experiments will be to measure the voltage of an "isolated" battery three different ways. (A battery is "isolated" if it is not connected to anything.)



Protek Multimeter First, we will measure the voltage of an "isolated" battery using the Protek multimeter as shown in the next picture.

In this laboratory, we will not give a complete description of the multimeter. Should you wish to know more about the multimeter than will be described in this lab, please read the manual. A copy of the manual should be at the workstation. Alternatively, the manual can be accessed either from the SP212 Lab Manual on the web or here via the link Manual for the Protek Multimeter.

1. Plug a black lead into the common input on the multimeter (marked COM) and a red lead into the voltage input (marked μA • V along with a handwritten Ω).

Warning: ***Please be careful***. The red lead must be plugged into the μA • V input. Please **do not** plug the red lead into either the 20A or the mA inputs.

2. Connect the multimeter across the battery by connecting the black lead to the black banana plug receptacle and connecting the red lead to the red banana plug receptacle.

3. Turn on the multimeter (red on/off switch) and turn the dial to $\overline{\overline{V}}$/LOGIC.

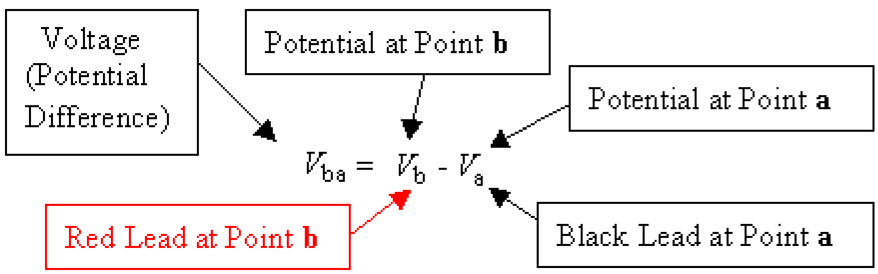
4. If the reading on the multimeter is negative, the battery is incorrectly installed in the battery holder.

To verify that this is the case, check that the positive end of the battery (marked with a + on the side of the battery) is connected to the red post (red banana plug receptacle) on the battery holder. If it isn't, reverse the battery.

For the remainder of the semester in laboratory, we will usually write voltages in the form V_{ba}. This notation is based on the alternative name for voltage, potential difference, so that we can think of V_{ba} as the potential difference between points **a** and **b**.

These words suggest the existence of an electric potential at point **b**, V_b, and an electric potential at point **a**, V_a. In fact, we define $V_{ba} = V_b - V_a$. We will deal with the concept of electric potential in detail in the third lab of the semester, *Equipotentials and Electric Fields*. Briefly, electric potential is potential difference relative to a reference position where the electric potential, V_a, is *defined* to be zero. However, we will not be concerned with electric potential in the present lab.

The voltage (potential difference), V_{ba}, is measured by placing the red lead (the "test" lead) at point **b** and the black lead (the "common" lead, COM=Common) at point **a**. Measured in this way, the voltage indicates the electric potential at point **b** relative to the electric potential at point **a**. Most of the discussion in the lab, thus far, is summarized in the next diagram.



5. In the space provided, record the reading on the multimeter. (If you are having difficulty, consult your instructor.) The uncertainty in the readings on the multimeter can be found in the [Manual for the Protek Multimeter]().

R1: V_{ba} = ± V

Remember that if we multiply V_{ba} by a charge, it gives us the change in electric potential energy of that charge as it moves from point **a** to point **b** then answer the following two questions.

R2: Consider the value of V_{ba} recorded in R1. Suppose that a positive charge moves from point **a** to point **b**. Does the electric potential energy of the positive charge increase or decrease?
◯ Increase ◯ Decrease

R3: Consider the value of V_{ba} recorded in R1. Suppose that a negative charge moves from point **a** to point **b**. Does the electric potential energy of the negative charge increase or decrease?
◯ Increase ◯ Decrease

6. Measure the voltage V_{ab}. (Yes, the red lead should be at point **a**, the negative terminal of the battery, and the black lead should be at point **b**, the positive terminal.) In the space provided, record the reading on the multimeter.

R4: V_{ab} = ± V

R5: How is V_{ab} related to V_{ba}?

Save your Responses

The value of V_{ab} should have been negative and this implies that the electric potential energy of a positive charge will decrease as it moves from point **b** to point **a**. Consequently, the electric potential decreases ($V_a < V_b$), hence the negative value of voltage. The potential decrease can be thought of as a "potential drop" from point **b** to point **a**.

Sometimes (often) we hear or read the term "voltage drop" associated with negative values of V_{xy}. That is *not correct* since what is really meant is potential drop i.e. a decrease in potential. The best way to remember this is that *voltage doesn't drop, potential does*. Unfortunately, even though voltage is introduced correctly in the textbook (page 592), later in the textbook (page 665, for example) the term "voltage drop" is occasionally used. This just proves that old habits die hard.

(Note: Voltage can drop if, for example, a positive value of V_{xy} becomes smaller i.e. the voltage is decreasing. This would be the case if a battery is "going dead" or someone is decreasing the voltage (turning down the dial) on a voltage source (power supply).)

Mastech Multimeter Next, we will measure a voltage using the Mastech multimeter. Again, we will not give a complete description of the multimeter. Should you wish to know more about the multimeter than will be described in this lab, please read the manual. A copy of should be at the workstation. Alternatively, the manual can be accessed either from the Lab Manual on the web or here via the link Manual for the Mastech Multimeter.

1. Replace the Protek multimeter with the Mastech multimeter. Plug the black lead into the common input (again marked COM) and the red ("test") lead into the voltage input (marked VΩHz) at the lower right of the meter.

Warning: Again, ***please be careful***. The red lead must be plugged into the ***voltage input***.

2. Turn the dial on the multimeter to the 2 on the V⎓ scale and turn on the multimeter.

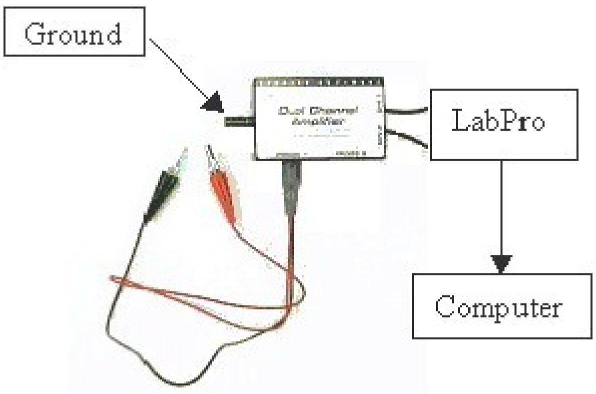
3. Measure V_{ba} using the Mastech multimeter. In the space provided, record the reading on the multimeter. The uncertainty in the readings on the multimeter can be found in the Manual for the Mastech Multimeter.

R6: V_{ba} = ________________ ± ________________ V

Save your Responses

Reversing the leads should give the same results as for the Protek so we won't bother.

Computer The equipment and software that we used extensively last semester, LabPro and LoggerPro, can also be used to measure voltage. The required "sensor" is shown in the next picture. As in the case of the multimeters, the red lead will be the "test" lead and the black lead will be the "common" lead. (It might be worth reviewing the operation of LabPro and LoggerPro as given in the first laboratory from last semester. A PDF version of that lab can be found at http://www.usna.edu/PhysicsCourses/SP21xSupport/211Lab0.pdf. A direct link to the lab is given here *Introduction to Laboratory*.) Let us make a voltage measurement with this system.



1. Plug a voltage probe into the PROBE 1 outlet of the Dual Channel Amplifier (DCA) as shown in the picture.

2. Plug the appropriate leads on the DCA into CH1 and CH2 on the LabPro.

3. It is important to always "ground" the DCA. This is accomplished by connecting the black banana plug receptacle on the side of the DCA to "ground." Plug one end of a wire into the black banana plug receptacle and plug the other end of the wire into a banana plug receptacle marked GND on the Pasco Digital Function Generator. 4. Boot the computer and start the program **LoggerPro**.

5. When the program starts, open the folder **Elec Intro** and open the file **Voltage**.

You will be pleased to know that it should never be necessary to "calibrate" the voltage probe. However, it is usually necessary to "zero" it. Adjust the zero as follows.

6. Create a "short" between the voltage leads by connecting them together.

R7: Why does this result in zero voltage between the red and black leads? (Hint: Refer to the definition of voltage.)

7. Click the mouse on **Experiment** in the menu at the top of the computer screen then click on **Zero**.

8. Connect the voltage leads to the battery as was done with the multimeters.

9. Click on **Collect**. The red cursor should proceed across the screen at an approximately constant value.

10. Adjust the vertical scale on the graph so that the voltage can be read to within about 0.01 V or use the **Statistics** function in the **Analyze** menu to obtain a value of the voltage. Record the value of the voltage in the space provided. Depending on the instructions from your instructor, either **Copy** the graph and **Paste** it into an **Excel** spreadsheet so that the upper left corner is in cell A1 of an **Excel** speadsheet or **Print** the graph. If you are using **Excel**, resize the graph so that the right edge does not extend beyond column J.

R8: V_{ba} = ± V

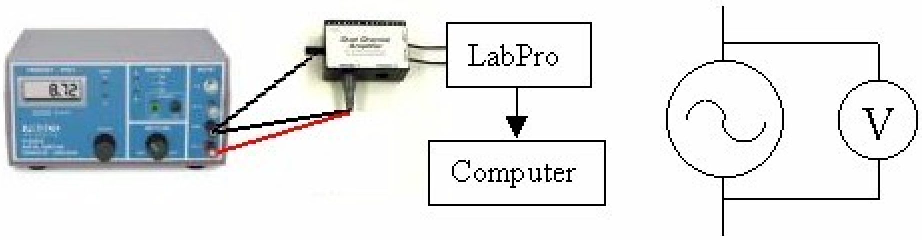
R9: Compare this value of the voltage with the two previous values of V_{ba}. (For reasons that will be given in the next lab, this value of V_{ba} should be lower than the other two values.)

Save your Responses

Measuring a Time-varying Voltage The computer is particularly useful for measuring time-varying voltages. Let us measure the voltage vs. time for an "isolated" time-varying voltage using the equipment shown in the picture on the left in the next diagram. The time-varying voltage is produced by a Pasco Digital Function Generator. The associated schematic is shown in the sketch on the right in the diagram.

1. Connect the black lead of the voltage probe to the GND terminal on the Pasco Digital Function Generator-Amplifier. The red lead can be connected either to HI Ω or LO Ω.

2. On the front of the function generator, turn the AMPLITUDE dial fully counterclockwise. (This sets the function generator to zero amplitude i.e. zero signal.) Using the switch on the back of the function generator, turn it on.



3. Adjust the frequency to 1.000 Hz. (Push the RANGE ∇ button twice then ADJUST the frequency to 1.000 Hz.) Turn the AMPLITUDE dial clockwise about a quarter turn.

4. Click **Collect** i.e. run the program. The voltage vs. time should be sinusoidal. If not, consult your instructor. Depending on the instructions from your instructor, either **Copy** the graph and **Paste** it into an **Excel** spreadsheet so that the upper left corner is in cell K1 of an Excel speadsheet or **Print** the graph. If you are using **Excel**, resize the graph so that the right edge does not extend beyond column U.

(Note: A sinusoidal voltage is sometimes known as AC voltage. It is interesting that AC is an abbreviation for "alternating current" and thus does not properly represent voltage. This is particularly true for our measurement where essentially no current is involved. Nonetheless, since there are no words to cause confusion and since the usage is so widespread, we will use the term "AC voltage" for a sinusoidal voltage.)

5. On the graph, indicate the period, *T*, the time for one cycle. (This can be done in **Excel** using the drawing tools.) From the graph, determine the period and use that to calculate the frequency, *f*. In the space provided, record the values of *T* and *f*.

R10: T = ________ ± ________ s

R11: f = ________ ± ________ Hz

R12: Compare the calculated frequency with the reading on the function generator.

6. Press the button on the function generator that makes it generate a "triangular" voltage.

7. Click **Collect**. Depending on the instructions from your instructor, either **Copy** the graph and **Paste** it into an **Excel** spreadsheet so that the upper left corner is in cell V1 of an **Excel** speadsheet or **Print** the graph. If you are using **Excel**, resize the graph so that the right edge does not extend beyond column AF.

R13: Describe the graph generated in step 7. In your discussion, include what are represented by the *x*- and *y*-axes. Also describe the shape of the curve.

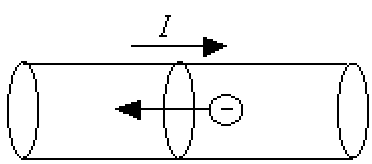
Save your Responses

II. Electric Current (Section 25-2 in the textbook) Our third goal in this lab is to learn about electric *current*. Electric current exists when there is a *net flow of charge*. (Sometimes (often) we hear or read the phrase "current flow." That is incorrect because current doesn't flow, charge does. That mistake is occasionally made in our textbook. See pages 638 and 664, for example.) There are two facts that we need to remember concerning electric current.

- The magnitude of electric current, measured in **amperes** (A) equals the rate at which charge, measured in **coulombs** (C) passes a given point in the circuit. If an amount of charge, ΔQ, passes a point in a time Δt, the average current can be calculated from $\bar{I} = \Delta Q/\Delta t$ (Text eq. 25-1a). The instantaneous current is given by $I = dQ/dt$ (Text eq. 25-1b).

- The direction of electric current is the direction of the flow of positive charge. (Yes, if it is electrons that are in motion, the associated current is the opposite to the direction of the motion of the electrons.)

To be sure that we understand the concept of electric current, suppose that there are electrons in a tube flowing to the left and suppose that we do some timing while we count the electrons as they pass by. If 6.25×10^{18} electrons flow to the left through the tube in 1.0 second, there is a current in the tube of approximately 1.0 A to the right.



R14: Carry out a calculation that shows that the magnitude of the current for this example is indeed 1.0 A.

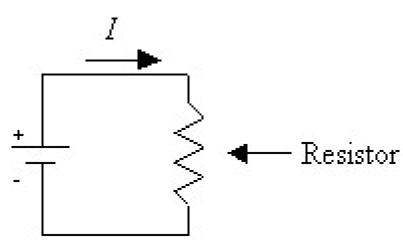
Save your Responses

In this course we will always try to create a "complete" path for the flow of charge. For example, a path is "complete" if the charge can return to where it started. A "complete" path for the flow of charge is easy to create using wires and resistors. (A resistor is a circuit element that opposes, but doesn't stop, charge flow. We will learn more about resistors in the next section of this lab.) We will be studying that kind of path in the first four labs of the semester. However, in the fifth lab, we will study a circuit element known as a capacitor. A capacitor is more subtle in that, as we shall see, a capacitor is a special device that can "complete" a path even though no charge can flow through it. Do not worry about that for now.

Any "complete path" or collection of "complete" paths is known as a *circuit*. Sometimes you will hear or read the phrase "open circuit" which means that the path is not "complete." That could be misleading since if the path is not complete, it is not a circuit. Similarly, the term "complete circuit" is redundant.

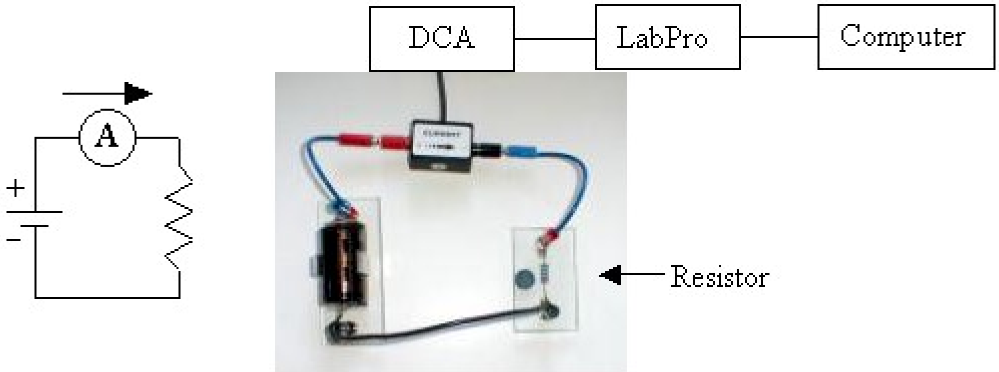
Measurement of Constant Current (sometimes referred to as direct current or DC) Our fourth goal in this lab is to learn how to measure current. An important consequence of the first "bullet" describing current is that electric current is completely defined by what is happening at a *single point* in a circuit. Consequently, in order to measure electric current, we must arrange things so that the charge (or a known fraction of the charge) flows through our measuring device. We accomplish this by *breaking into the circuit so that the charge must flow through our measuring device*. (This is sometimes referred to as putting a measuring device into a circuit in *series*.)

For the remaining measurements in this lab, the circuit that we will study consists of a battery and a resistor. The circuit and direction of the current, *I*, is shown in the next diagram. Note that positive charge flows outside the battery in the expected direction since like charges repel i.e. outside the battery, positive charge flows away from the positive terminal of the battery.



Note: For a practical reason (Too much current blows fuses and it is easy to blow fuses in the multimeters.), we will **not** use the multimeters to measure current this semester. Consequently, there should be **no** reason to use the inputs at the bottom lower left of the multimeters i.e. please **do not** plug leads into the 10 A, 20 A or mA inputs of the multimeters.

Again, since we wish to measure current, we know that we must arrange things so that the charge flows through our meter. The symbolic representation of what we will construct is shown on the left in the next diagram. The circle with the "A" in it will be our device for measuring current and is often referred to as an "ammeter." The actual equipment that we will use to measure current is shown on the right in the next diagram. The computer can measure an electric current (serve as an "ammeter") by using a current probe with the DCA and LabPro.



1. Plug a current probe into the PROBE 2 outlet on the DCA. (A current probe is shown in the picture. Also, for convenience, leave the voltage probe plugged into PROBE1.)

2. In **LoggerPro**, open the **Current** file.

3. Adjust the zero as follows. With nothing connected to the current probe, click the mouse on **Experiment** in the menu at the top of the computer screen then click on **Zero**.

4. Using a resistor with three red stripes and one black stripe, construct the circuit shown in the previous diagram. (We will learn more about resistors in Part III of this lab.) Be sure to orient the current probe so that the arrow drawn on it is in the direction of expected positive charge flow (current).

5. Click on **Collect** to start the program. Depending on the instructions from your instructor, either **Copy** the graph and **Paste** it into an **Excel** spreadsheet so that the upper left corner is in cell AG1 of an **Excel** speadsheet or **Print** the graph. If you are using **Excel**, resize the graph so that the right edge does not extend beyond column BD.

6. Determine the value of the current from the graph and record the value of the current in the space provided for I_{forward}.

R15: I_{forward} = ± A

Save your Responses

7. Reverse the orientation of the current probe, click on **Collect** and record the value of the current in the space provided.

R16: I_{reverse} = ± A

R17: Do your results confirm that the arrow on the current probe indicates the direction of the current?
○ Yes ○ No

Explain.

8. Click on **Collect**. When the computer is about half way through recording the data, disconnect one of the leads to the battery.

R18: What happens to the current when the lead is disconnected?

Explain.

Save your Responses

III. Resistance (Section 25-3 in the textbook) Our fifth goal in this lab is to learn about resistance. A resistor is a circuit element that opposes (resists) charge flow. In fact, the resistance is *defined* by

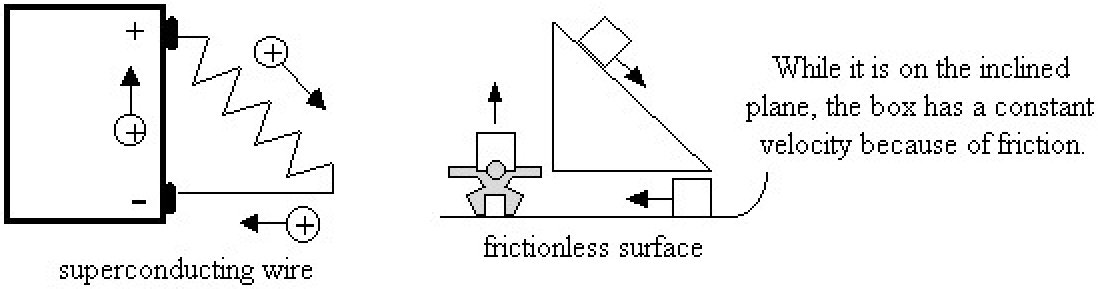
Text eq. [25.2a]
$$R = \frac{V}{I} \tag{1}$$

In this equation V is the *magnitude* of the voltage across the resistor and I is the *magnitude* of the current through the resistor so that the resistance is always positive. The unit of resistance is the **ohm** (Ω). (Equation (1) is not Ohm's law. Ohm's law is that many materials behave such that R is a constant, independent of V and I.)

R19: Explain clearly how equation (1) represents the fact that a resistor opposes charge flow.

Save your Responses

The fact that a resistor "opposes" suggests similarities with friction. Consequently, the next diagrams might be helpful in understanding resistance (and voltage and current).



In the circuit, the resistor can be drawn in any orientation (at any angle relative to the horizontal). The reason is that the charge loses mostly electric potential energy as it moves through the resistor so that, as before, it might be useful to think of the charge as massless. (Also, the charge is actually moving through (inside) the resistor.) Consequently, there is no "physics" reason that the resistor is drawn at an angle. It is drawn that way only to emphasize the analogy between it and the inclined plane with friction shown to the right of the circuit.

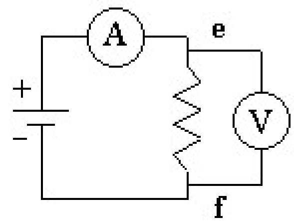
The two new parts of the analogy (inclined plane with friction and horizontal frictionless surface) are fairly accurate. Specifically, both the resistor and the inclined plane "heat up" as the charge and mass lose potential energy. (Also, both the charge in the resistor and the box on the inclined plane move with a constant speed. In the case of the box, the angle of the inclined plane is chosen so that the velocity is constant.) Finally, neither the superconducting wire nor the frictionless surface provides any "resistance" so that both the charge and mass return to the starting point without losing further energy.

Resistance Measurements Our sixth goal in this lab is to learn how to measure resistance. We will measure resistance two ways. First, we will measure the voltage *across* the resistor and the current *through* the resistor and use the definition (eq. 1) to calculate the resistance. Second, we will use a multimeter to measure the resistance directly. Before making the measurements, however, let us predict what the resistance should be.

1. Use the standard color code for resistors to determine the resistance and uncertainty in the resistance for the resistor. One version of the standard color code is found on page 639 in the textbook. A link to another version can be found at the bottom of the SP212 Lab Manual. That link is reproduced here Resistor Color Code. Record the predicted value of the resistance and uncertainty in the resistance in the space provided.

R20: $R_{\text{Color Code}}$ = ______________ ± ______________ Ω

Next, we will measure the voltage *across* the resistor and current *through* the resistor via the circuit shown in the next diagram. (Note that this assumes that there is no current in the voltmeter. That would be the case for a perfect voltmeter.) We will use the computer for both measurements.



1. Both the voltage probe and current probe should still be connected to the DCA. If not, connect them now.

2. Open the file **VoltCurr**. Be sure that the voltage leads are "shorted" and that nothing is connected to the current probe then **Zero** both probes.)

3. Construct the circuit. Be careful about the placement of the voltmeter. For reasons that will become apparent in the next laboratory, the results will not be correct if the voltmeter is placed across the battery. Place the black "common" lead at point **e** and the red "test" lead at point **f**. Since the current is from point **e** to point **f**, this is known as measuring the voltage along the direction of the current.

4. Click **Collect** i.e. start the program.

5. Record the values of the current and voltage in the space provided.

R21: I = ______ ± ______ A

R22: V_{fe} = ______ ± ______ V

V_{fe} should be negative. This is a general result that we will use many times through the semester. Namely, for a resistor the voltage measured along the direction of the current is negative. Conversely, the voltage measured opposite the direction of the current is positive.

For this experiment, the *current* will be negative or positive depending upon which way the arrow of the ammeter was pointing in your circuit.

6. Use eq. (1) to calculate the resistance and record the value in the space provided.

R23: $R_{calculated}$ = ______ ± ______ Ω

R24: Does calculated value of resistance agree with the value predicted from the Color Code?
◯ Yes ◯ No

Discuss.

Save your Responses

Finally, we will measure resistance using a multimeter. In this case, measurements are made *across* a resistor with the resistor "isolated" i.e. not connected to anything.

1. Remove the resistor from the circuit.

2. Be sure that the leads of the Protek multimeter are plugged into the appropriate inputs (black lead in the common input (marked COM) and the red lead in the voltage/resistance input (marked μA • V along

with a handwritten Ω)) and be sure that the leads are not connected to anything else.)

3. Turn the dial to Ω/ •))) and turn on the multimeter.

4. Simultaneously touch one end of the resistor with the red lead and the other end of the resistor with the black lead. Record the reading on the multimeter in the space provided.

R25: R_{Protek} = ________ ± ________ Ω

R26: Compare this value with the previous two values of the resistance.

R27: From what we have learned about the multimeters and resistance, discuss what the resistance of a voltmeter should be i.e. discuss whether the resistance should be large or small and why.

R28: From what we have learned about the multimeters and resistance, discuss what the resistance of an ammeter should be i.e. discuss whether the resistance should be large or small and why.

Save your Responses

IV. Light bulbs--Special resistors As an exercise and test of our understanding, we will study a light bulb when it is glowing. In order to preserve the battery, please make the light bulb glow for as short a time as possible.

1. For the last circuit that we studied (It is probably still wired.), replace the resistor with the light bulb. The light bulb should glow. If not, consult your instructor.

2. Measure the voltage *across* the light bulb and the current *through* the light bulb and record them in the space provided.

R29: $I_{\text{Light Bulb}}$ = ________ ± ________ A

R30: $V_{\text{Light Bulb}}$ = ________ ± ________ V

3. Calculate the resistance of the light bulb and record it in the space provided.

R31: $R_{\text{Light Bulb}}$ = ± Ω

R32: Is the resistance of the light bulb "large" or "small" compared with the resistance of the resistor.

R33: It should be clear that the light bulb has some of the characteristics of a resistor. Of course, there is something special about the light bulb in that it glows. Explain clearly why the light bulb glows.

End of Lab Checkout Before leaving the laboratory, please dismantle any circuits or connections that you have made. Place the wires in one pile and return the meters to their boxes.

Submit Answers